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A GUIDE TO GOOD PRACTICE FOR MINIMUM
ODOR AND SMOKE FOR DIESEL POWERED
VEHICLES

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A GUIDE TO GOOD PRACTICE FOR MINIMUM ODOR AND SMOKE FROM DIESEL POWERED VEHICLES

INTRODUCTION

In our air pollution conscious country, the public is aware of all vehicle emissions—particularly those they see or smell. Diesel-powered vehicles account for less than 1 percent of vehicle registrations and less than 5 percent of the fuel consumed by highway vehicles. Nonetheless, millions of Americans each year have some exposure to or contact with diesel vehicles. The fact that such a large number of people are exposed to objectionable diesel exhausts means that adverse reactions or complaints have reached significant proportions.

It must be emphasized that diesel odor and smoke are nuisance-type emissions, which in themselves possess no known significant health hazard. Like any air pollutant, however, they should be minimized.

Regulations continue to be established and enforced at all levels of state and local government to reduce smoke from motor vehicles, particularly the diesel. These regulations are indications that excessive smoke from diesel-powered vehicles will not be tolerated in this country. Although there is currently no Federal control standard for diesel odor, such a requirement is expected in the future for diesel engines used in vehicles.

The purpose of the "Guide" is to help minimize smoke and odor emissions from diesel-powered vehicles. To do this effectively, a team approach is required; and everyone on the team is important. Starting with the selection of the power package and fuel, through maintenance and driver performance, each person must do his part if the public image of the diesel and its operators is to be improved.

The following pages contain practical information and recommended practices to aid in this task. These guidelines are a result of a detailed study of available literature and reports pertinent to diesel smoke and odor, as well as interviews with engine and vehicle manufacturers, fuel and additive suppliers, fleet operators, and enforcement agencies. Presented in separate sections are general characteristics of diesels, guidelines for minimum smoke and guidelines for minimum odor.

GENERAL CHARACTERISTICS OF DIESEL ENGINES

The diesel engine is available in a variety of designs, but all operate on the compression ignition principle in which air is compressed and liquid fuel is injected under high pressure. The high-temperature mixture self-ignites with resultant power output from the engine. Both two-stroke (one power stroke per cylinder each engine revolution) and four-stroke (one power stroke per cylinder every two engine revolutions) are used. Diesels may be naturally aspirated (air is inducted from the atmosphere without external assistance) or turbocharged (exhaust energy used to power a turbine air compressor to increase the amount of air per engine stroke). In all but the turbocharged diesels, the amount of air inducted is dependent on the engine speed because there is no throttle in the inlet air system as there is in the gasoline engine.

The amount of fuel injected determines the power output. At idle, very little fuel is used; at high speed (high power output), more fuel is needed. A convenient way to think of the diesel with respect to the gasoline engine is to consider air-fuel ratio, which is defined as

$$\text{air-fuel ratio} = \frac{\text{amount of air}}{\text{amount of fuel}}$$

in the cylinder available for combustion. An air-fuel ratio of about 100:1 exists during idle, but, under power conditions, the ratio is on the order of 20:1. Since this ratio is greater than 15:1, the air-fuel ratio at which the correct amounts of air and fuel are present for complete combustion, the diesel may be considered to operate *air-rich* as shown in Figure 1.

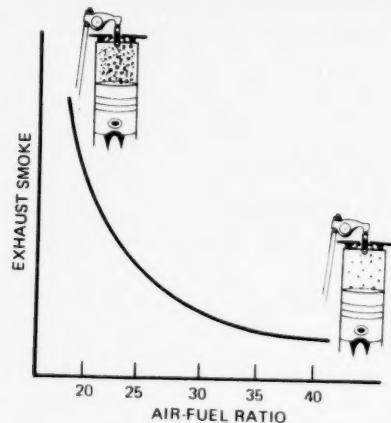


Figure 1. Effect of air-fuel ratio on smoke

As shown in Figure 2, the sources of air pollution can be categorized as either stationary (industrial, domestic) or mobile (automotive). Mobile sources such as cars, trucks, and buses account for about half of the total emissions to the atmosphere.

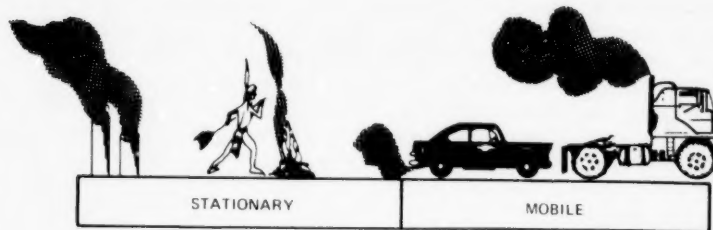


Figure 2. Relative contribution of various sources to air pollution

Of the total air pollution from moving sources such as gasoline-powered cars and trucks, aircraft, and others, the contribution of diesel engines is relatively minor, as illustrated in Figure 3.

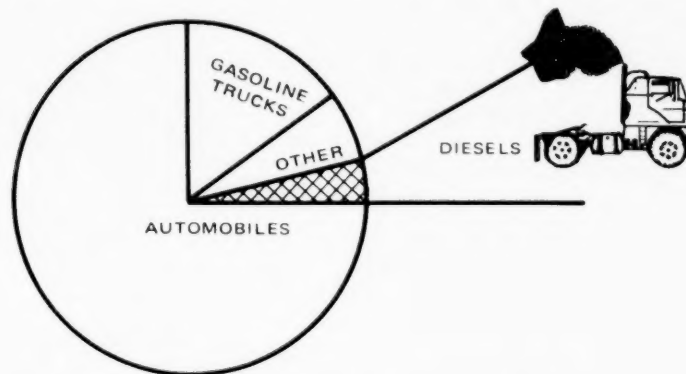


Figure 3. Diesel engine contribution to air pollution from mobile sources

The bar chart, Figure 4, compares in general the various emissions from a gasoline- and a diesel-powered vehicle in relative terms. It is not commonly known that the diesel emits far less toxic carbon monoxide (CO) and smog-forming hydrocarbons (HC) than the gasoline engine. Oxides of nitrogen (NO_x) are about the same as those for the gasoline engine. The nuisance-type odor and smoke emissions, however, are much greater from the diesel than from the gasoline engine. Smoke may be emitted when some diesels are

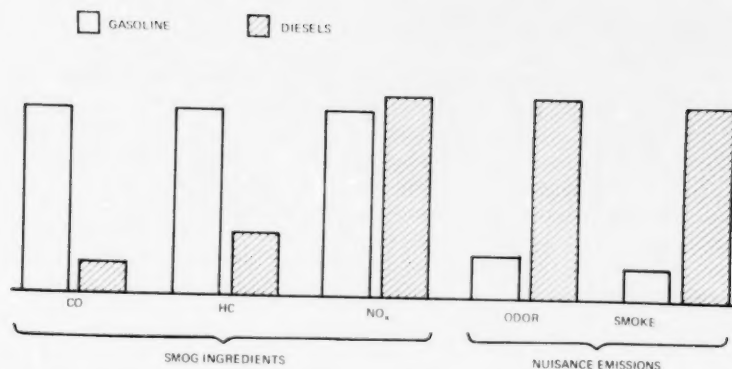


Figure 4. Comparison of emissions for diesel and gasoline engines

operated with an air-fuel ratio less than about 25:1. Odor has not, however, been directly related to air-fuel ratio.

TYPES AND CAUSES OF SMOKE

Smoke is generally the result of incomplete combustion. The three types of smoke are:

1. **White or Cold Smoke**—Unburned droplets of liquid fuel usually associated with startup or idle for some engines.
2. **Blue Smoke**—Unburned engine oil that reaches the combustion chamber because of worn piston rings, cylinder liners and/or valve guides. Partially burned fuel may also be included.
3. **Dark, Black, or Hot Smoke**—Unburned carbon particles (soot) usually associated with engines at operating speeds, loads, and temperatures.

White or cold smoke can be reduced by minimizing idle time, especially after initial startup, and using fuel with ignition properties suitable for the prevailing temperatures. Indoor parking and engine-block heaters also reduce cold smoke. Engine maintenance or overhaul can generally eliminate the occurrence of blue smoke. Black smoke is the most common and predominant type and is of principal concern. Black smoke is always related to incomplete combustion.

DIESEL ENGINE CHARACTERISTICS

TYPES AND CAUSES OF ODOR

The chemical composition of the exhaust constituents causing odor has not been identified. It is also difficult to describe diesel odor. In fact, panels of trained observers are needed to judge odor quality and intensity because there is no instrument available for its measurement. Just as the method of expressing or describing odor is far from satisfactory, the exact causes of odor are not well understood. Placement of the exhaust outlet in the design of the vehicle can alter the intensity of the odor. Not only is the natural dilution of the odor influenced but its presence and availability to the public are varied.

GUIDELINES FOR MINIMUM SMOKE

The following guidelines are presented under categories of engine application, derating, maintenance, driver effects, fuel, and control methods to aid the purchaser, operator, mechanic, and driver of diesel-powered vehicles.

EFFECT OF ENGINE SIZE AND APPLICATION ON SMOKE

The selection of diesel engines for trucks and buses is often more art than science although engine manufacturers provide excellent guides for specific applications. Unfortunately, the manufacturer's recommendations are sometimes used merely as rough approximations, especially when vehicles are purchased through competitive bidding. In order to save \$100 to \$500 on a vehicle costing \$20,000 to \$30,000, it is not unusual to select a slightly smaller engine than needed. It should be remembered that:

Diesel-powered vehicles generally need and utilize all the power available whereas gasoline-powered passenger cars utilize only a fraction of the power available.

The underpowered vehicle is shown in the cartoon in Figure 5. Too small an engine often leaves no allowance for higher route speed, greater loads, or engine performance deterioration. When more power is required, overfueling is employed. Because overfueling causes more exhaust smoke, the operator should never adjust the fuel delivery beyond that specified by the manufacturer. As is the common belief, power and smoke are related; but, as shown in Figure 6, smoke increases greatly (from 2 to 3) for a small increase in power (1 to 2).



Figure 5. Peanut-sized diesel make heap big smoke !

Depending on the smoke characteristics of the engine, the increase in power or amount of overload not only can generate excessive smoke but also can cause possible mechanical damage to the engine. If the engine is too small or marginal, it will often be fully loaded, with the net effect of more smoke production.

The selection of engines for vehicles that must operate at varying elevations is also important from a smoke standpoint. Some types of engines are fairly insensitive to altitude; others produce significantly more smoke at higher altitudes. Some general characteristics for naturally aspirated and turbocharged engines are shown in Figure 7. As indicated by the figure, a naturally aspirated engine that produces very little smoke at sea level may

produce only moderately more smoke at 5000 feet and another type engine, if producing about 20-percent smoke opacity at near sea level, may produce as much as 40-percent opacity at 5000 feet. The turbocharged engine is generally considered to be less sensitive to altitude than many naturally aspirated engines.

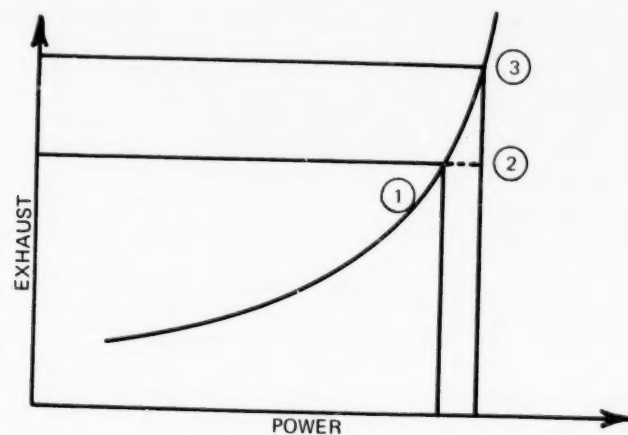


Figure 6. Smoke and power output of some naturally aspirated engines

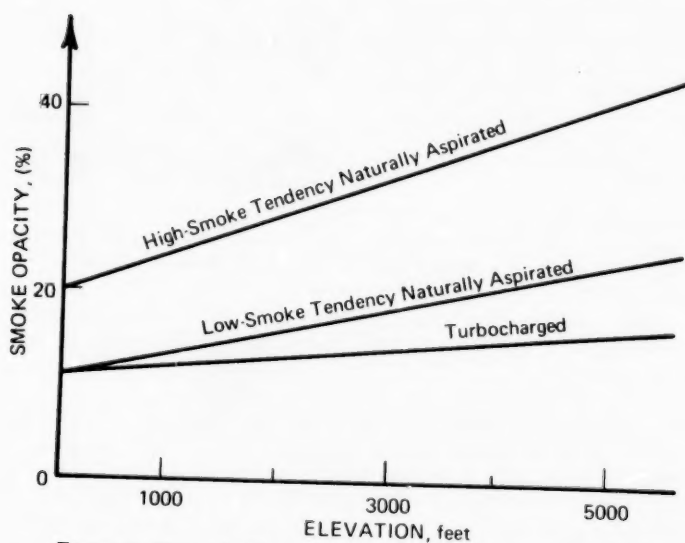


Figure 7. General effect of elevation (altitude) on smoke opacity

It would appear that naturally aspirated engines with known low-smoke characteristics and turbocharged engines would be the best selection for operation at higher elevations. The turbocharged engine, however, has a greater smoke tendency during initial acceleration. If a vehicle is consistently operated at a high altitude for which it has been adjusted and is engaged in stop-and-go service, a low-smoke-tendency naturally aspirated engine may contribute less overall smoke than a turbocharged engine. On the other hand, if a vehicle is to operate under cruise-type conditions, the turbocharged engine would produce lower smoke at that altitude than the naturally aspirated engine.

ENGINE DERATING CAN HELP TO MINIMIZE SMOKE

Engine derating is one of the most widely used methods for the reduction of visible smoke. Derating means reducing the available power or rating of an engine and is normally accomplished by reducing the amount of fuel injected per stroke throughout the operating speed range of the engine. Changing to smaller injectors, reducing fuel delivery pressure, or making other fuel-pump calibration changes can all reduce exhaust smoke.

The characteristics of some engines is to increase the smoke output with an increase in engine speed (Figure 8a); the reverse is true for other engines (Figure 8b). The usual effect of engine derating is to reduce smoke output throughout the operating speed range as shown by the dashed lines in Figure 8.

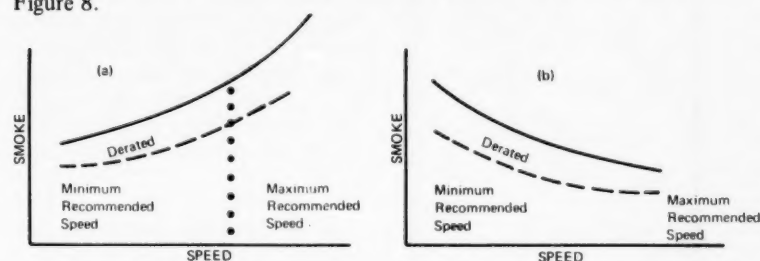


Figure 8. Effect of engine operating speed on maximum-power smoke for naturally aspirated engines

For some types of engines, a reduction in the maximum recommended or rated speed will result in less smoke in that part of the speed range by just "lopping-off" the high part of the curve. This effect is indicated by the dotted line in Figure 8a. Derating by this method does not change the power available within the remainder of the operating speed range and has been used with some success by a few operators. In any event, these engine derating changes generally involve injector replacement, fuel pump calibration, governor setting, or a combination of these. If this type of servicing is done in the field, it should be accomplished at an authorized service center.

Many fleet operators intentionally buy vehicles with derated engines because they realize better fuel economy and extended engine life, with less maintenance. These operators find that a nominal increase in initial cost is more than compensated for on a strict economic basis. Others find that adding a turbocharger to certain engines permits operating at the same power output but with reduced overall smoke and improved fuel economy, or increased power with an acceptable level of smoke.

FUEL SYSTEM MAINTENANCE AFFECTS SMOKE

One of the advantages of the automotive diesel engine is its ability to operate at high horsepower levels for long periods of time with little or no attention. Maintenance (Figure 9) for the diesel usually involves the fuel

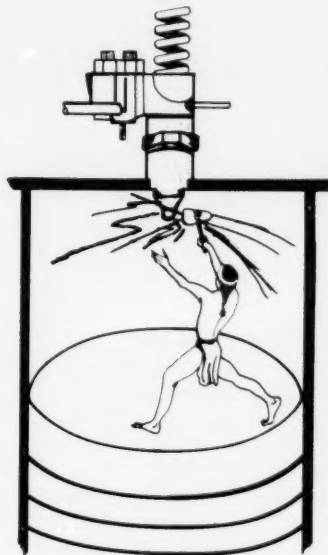


Figure 9. Tomahawk no fixum!

injection system or air induction system (covered in the next section). The condition of the fuel injection system has a most pronounced effect on engine smoke output. The fuel injection system is probably subjected to more abuse and misuse than any other part of a diesel engine. The fuel system includes the tank, delivery, and return lines, primary and secondary fuel filters, transfer and injection pumps, and injectors. The injection system on engines having the "unit type" injector includes a mechanical assembly to actuate the injector. An injector often operates satisfactorily for well over 100,000 miles.

Injectors atomize the liquid fuel by forcing it under very high pressure through small holes at a prescribed time during the cycle. Whatever happens during operation to alter spray characteristics, start of injection, duration or end of injection may alter engine

performance and the visible smoke. Sticky or worn injectors that do not seal tightly, have lost their preload due to wear, or otherwise do not permit clean injection with a full spray pattern can increase smoke and odor, lubricating oil contamination, and engine wear. Carbon deposits on the injector may also distort the spray pattern and cause more smoke.

In order to minimize odor and smoke, some maintenance departments have a rigorous program for periodic injector replacement and repair. Bench

test equipment is employed to flow balance and match injector delivery rate, spray pattern, and penetration. Bench test equipment is also used to flow check and calibrate injection pumps on a periodic basis. The net effect is to control tolerances to assure that fuel is injected into each cylinder in a similar way. The additional cost of maintenance has paid dividends in longer engine life, lower fuel consumption, and reduced smoke and odor.

Some unit injection systems have a number of wear points in the mechanism that actuates the injector. These systems operate from the camshaft of the engine, and, as wear develops, the start of injection takes place increasingly later. The net effect is that the fuel is delivered into the combustion chamber later than necessary for good combustion. Late injection generally results in dense smoke; for some engines, this problem is most pronounced at low engine speeds. For others, it is more pronounced at higher engine speeds. Cleaning or replacing the injectors is only part of the maintenance necessary to the injection system; the manufacturer's installation and adjustment specifications also should be strictly followed.

In some applications where injection timing deteriorates more rapidly than the injector, it is desirable to check timing and adjustments more often or to advance the timing slightly to compensate for wear. Slight advances in timing should be accomplished with judgment and caution because of the tendency to increase the peak pressures within the engine and reduce engine life.

INDUCTION AND EXHAUST SYSTEM MAINTENANCE AFFECTS SMOKE

Many times, injectors are blamed for poor performance and excessive smoke when in reality the induction and exhaust system of the engine needs attention. Maintenance of these parts of the engine is generally straightforward and easier to accomplish than maintenance of the injector system. The general effect of inlet and exhaust restriction on smoke and power is shown in Figure 10. Some engines, particularly naturally aspirated engines, are quite sensitive to both intake and exhaust restrictions. Restriction of the

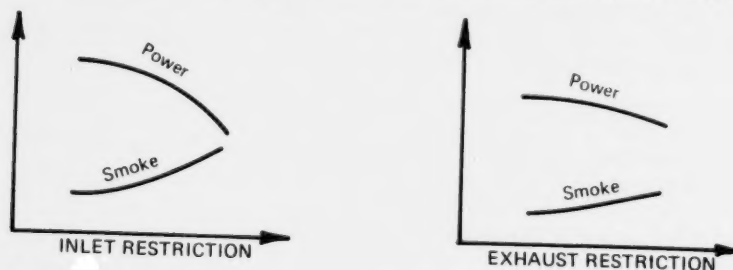


Figure 10. General effect of inlet and exhaust restriction on smoke and power

intake system not only affects smoke output of some engines; it can also be a definite economic factor in terms of available power. Exhaust restrictions have less effect and on some types of engines almost no effect. A restriction of either the intake or outlet tends to increase exhaust temperatures and make scavenging of the combustion chamber less efficient. The vehicle and engine manufacturers work together during design and installation to insure that induction and exhaust systems do not penalize performance.

If the air cleaner is too small or becomes clogged, the engine will not induct enough air. This lowers the air-fuel ratio, increases smoke (Figure 11) and exhaust temperatures, and reduces power.



Figure 11. Choked "injun" no can breathe!

The induction system may include a turbocharger, which uses energy in the exhaust gases to force air into the engine. When the exhaust gases contain insufficient energy such as during acceleration from idle, the turbocharger may not provide a full air charge.

Valving in the intake and exhaust systems also plays an important part in the ability of an engine to breathe and its resultant smoke production. If valve underheads become clogged with deposits, the resultant internal restriction may ultimately require cylinder head rebuilding. Worn valve guides and bushings, and piston rings and liners can permit excessive oil consumption, which can produce blue smoke, in addition to black smoke. Persistent blue smoke under cruise conditions may indicate the need for major overhaul.

Service manuals, supplied by engine manufacturers, contain a wealth of information on maintenance practices to control smoke. This information ranges from troubleshooting hints for determining the cause of smoke to detailed specifications and tolerances on working parts. Use of these manuals is essential in establishing preventive maintenance programs, training diesel mechanics, and assisting in day-to-day repairs.

EFFECT OF DRIVER TECHNIQUE ON SMOKE

Interviews with drivers, driver supervisors, and fleet operators, have indicated the need to clarify a common misconception.

Smoke does not always mean power!

Except for drivers who have operated vehicles in states that have active smoke enforcement programs, this is probably the most misunderstood fact about a

diesel. As pointed out earlier, a very slight increase in available power could result in a substantial increase in visible smoke. This is illustrated in a slightly different way by Figure 12. The fact is that when an engine cannot take in more air to support combustion efficiently, the small increase in horsepower is at a very high cost in both fuel consumption and smoke.

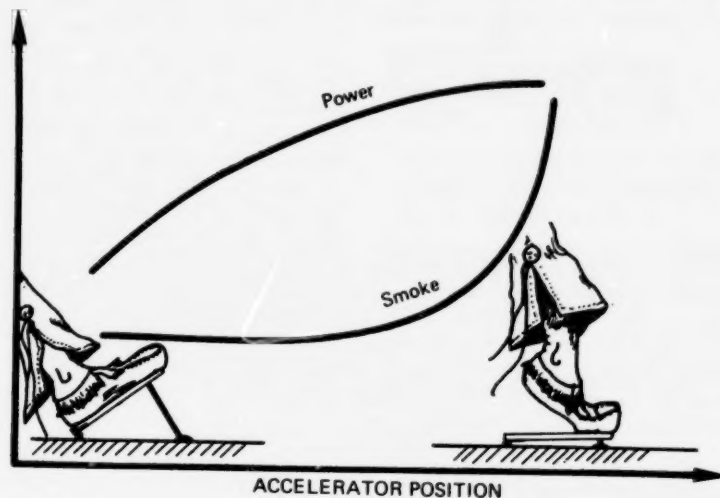


Figure 12. Smoke and power as affected by accelerator position

Rather than make road adjustments, which increase the level of smoke, the driver should report and persist in his complaint of poor performance or lower power to the maintenance and driver supervisors until the cause is found and remedied. Chassis dynamometers, often used by service garages, are helpful in determining the power available at the rear wheels. Overfueling of the engine by road adjustment or by alteration of fuel pumps, delivery pressures, or injector backpressure merely delays the application of correctly sized engines or accomplishment of necessary maintenance and, in the meantime, contributes to the diesel smoke problem. The fleet operator or superintendent who observes smoke issuing from his diesel equipment should recognize that more than smoke is going up the stack (Figure 13). Smoke can mean poor vehicle performance, reduced life, increased maintenance, poor public relations, and smoke citations.

Most drivers are warned that they should "keep the engine speed up" to reduce smoke. Underspeeding the engine at full load, commonly called "lugging," may result in more smoke and can cause undue mechanical stress and eventual damage. The driver should develop the habit of operating within the manufacturer's recommended speed range.

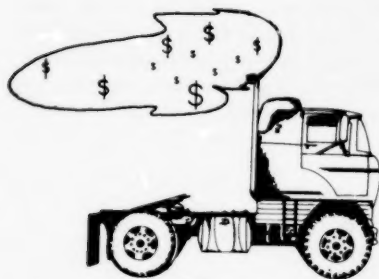


Figure 13. Plenty wampum go up in smoke! (Where there's smoke, there's fine\$!)

Driver technique can greatly influence the amount of smoke produced depending on the occurrence and duration of maximum power requirement. In most instances, however, this is established by the load, power train configuration, and the type of route over which the driver is required to travel. During acceleration, the driver can minimize puffs of smoke as well as the duration of the smoke by accelerating gradually when possible. For truck-tractors equipped with vertical stacks, some fleets have

installed a special mirror aimed at the tip of the exhaust pipe. This mirror permits the driver to "feather" the accelerator pedal during acceleration and cruise conditions to minimize smoke. When a loaded vehicle is negotiating a hill or is trying to maintain a minimum route speed and keep traffic flow orderly, the maximum available power from the engine may be required. The driver has no alternative but to operate the vehicle at its maximum smoke condition.

EFFECT OF TYPES OF FUEL ON SMOKE

Diesel fuel is usually available as a Number 1, which is a light or kerosene-like fuel, or as a Number 2, which is a heavier fraction. Number 1 is sometimes used in urban, stop-and-go-type, moderate-duty applications. Number 2, because of lower cost and higher heat content, is used almost exclusively by line-haul trucking and other applications where continuous high power output is required. The principal guideline for fuel selection is that the fuel be selected to conform to specifications around which the engine was designed.

The most important fuel properties are volatility, gravity, viscosity, ignition quality or cetane rating, and hydrocarbon composition. Volatility or distillation range is a measure of the vaporization characteristics of the fuel. Substitution of a low-boiling-range, low-gravity Number 1 diesel fuel for the heavier, higher-boiling-range Number 2 fuel in a diesel engine without fuel rate adjustment generally will result in noticeably less smoke. This is not accomplished, however, without a loss in power and, as such, is a type of derating. Fuel is injected by volume; and if less weight is injected (fewer Btu's), then less smoke and power will result. Fuels with too high a specific gravity or those having too high a maximum boiling point may cause excessive carbon deposits and exhaust smoke.

Viscosity is an important property since it influences the flow and lubricating properties of the fuel. This is critical in the fuel delivery system, particularly in the injectors where it affects spray pattern development and penetration. Use of lower viscosity fuel than recommended may result in leakage by the plunger during the downstroke of some unit injectors with reduced fuel delivery, less power, and less smoke. The combination of viscosity (in affecting droplet size) and volatility (in eventual evaporation of droplets) can affect combustion efficiency and, hence, exhaust smoke. Ignition quality or cetane rating varies in importance with differing engine designs.

It goes without saying that the fuel should be free of foreign matter such as water, dirt, or other particulate and that its quality should be uniform and dependable. Although quality fuels are available from all major producers, contamination may occur in storage, where moisture and corrosion can build up in fuel lines and tanks. To protect the finely machined components of the fuel injection system, there are usually at least two fuel filter elements located in the fuel supply system. A primary filter is usually located near the fuel tank followed by a secondary filter. Some types of injectors have a screen in the body of the injector for final filtration. In addition to routine cleaning or replacement of the fuel filters, routine cleaning or draining of the vehicle fuel tanks is recommended. The suction pipes through which the fuel is drawn from the tank should clear the bottom of the tank to avoid picking up water and sediment. Dispensing and storage tanks must be included in a successful fuel cleanliness program.

A number of commercial diesel fuel additives for reduction of visible smoke are available, and some are effective. Smoke has been reduced to approximately one-half of its original value by merely adding one of the commercial additives to the fuel. The improvement is almost instantaneous and has been demonstrated throughout an extended fleet test with *one* popular type engine to have no adverse effect on engine performance, injector wear, engine deposits, or other maintenance factors.

The increase in fuel cost of 1 to 2 cents per gallon for the more effective additives is viewed by a number of operators as prohibitive, and they prefer other means to reduce smoke. Some use fuel treatment as a temporary means until more permanent corrective action can be taken.

Some additives are excellent dispersants and will suspend water and sediment in the fuel and sometimes tend to plug the primary filter. One supplier recommends thoroughly cleaning all tanks before use. In addition to reducing smoke, tests have shown that injector life has been extended with certain types of additives with the potential for lower maintenance costs. The use of fuel additives, other than those approved by the manufacturer, may void the engine warranty of some makes. There is concern that the use of certain additives may result in products of combustion, the consequence of which is not completely understood in the atmosphere and human body.

EFFECT OF CONTROL DEVICES ON SMOKE

A number of devices and techniques have been offered to reduce smoke emissions. The effect of turbocharging, discussed previously, is beneficial, particularly during cruise-type conditions. During accelerations, rack limiters or aneroid controls are helpful in maintaining the air-fuel ratio for best performance and smoke control. Some manufacturers offer turbocharging kits, which have been added by some operators to existing engines. Though the kit permits uprating the engine power, this is usually not done when full smoke reduction potential is desired.

Dual fuel or fumigation systems utilizing liquified petroleum gas (LPG) have found limited application in diesel trucks. These systems meter a small amount of LPG into the intake manifold to initiate precombustion reactions which help the injected diesel fuel to burn better. Though the use of LPG brings about some reduction in smoke, the need for a dual fuel supply limits the popularity of this system. Further, the warranty may be voided because of the potential for overfueling with the LPG fumigation system.

A number of methods have been tried to modify the appearance of the smoke plume. Some operators discharged the smoke down in the vicinity of the drive wheels to dissipate the smoke, only to find the smoke looked worse. In many cases, the downward directed exhaust smoke was not only more noticeable, but it obscured the visibility of other motorists and, depending on design, entered the vehicle cab and aggravated the driver. Some operators of properly maintained stop-and-go-type vehicles have found downward directed or horizontal low to the ground exhaust is better than vertical stacks by keeping the soot out of the air and from falling on people and property.

Other methods included adding fresh air to the exhaust pipe to dilute the smoke, or using a number of small pipes to break up the single plume. Small, large, and various shaped pipes with novel arrangements for inducing dilution air have also been tried. None of these have been satisfactory and, more often than not, made the smoke more noticeable.

A potential key to reduced odor and smoke lies in improved component matching and wider usage of automatic transmissions. The heavy-duty automatic transmission is expected to improve driveability, route speed, and maintenance. Its use may reduce odor and smoke considerably by consistently preventing the engine from being overloaded throughout its speed range.

Passing the exhaust through afterburners or catalytic mufflers has been considered. These devices lack technical promise for smoke control because of the need for very high temperatures for oxidation of the carbon particulate. Electrostatic precipitation of carbon particulate has been tried with diesel exhaust, but has not proved practical. The carbon particulate quickly coats the interior and short-circuits the system. Mechanical filters and

separators have also been proposed for removal of smoke from the exhaust stream. These methods usually increase exhaust back-pressure beyond allowable limits or they are gravely inefficient and involve considerable cleaning and repair.

Federal smoke requirements for 1970 diesel engines have been met without external devices or equipment such as those mentioned. The procedure includes a 1000-hour run to demonstrate that the engine will continue to meet the smoke limits with time. Accordingly, the need for external devices for control of smoke from 1970 and later engines to meet Federal smoke levels should not be necessary if application, maintenance, operation, and fuel are in accord with manufacturer's recommendations.

GUIDELINES FOR MINIMUM ODOR

Guidelines for minimum diesel odor are substantially more difficult to generalize than those for smoke because less is known about causes and factors influencing diesel odor. Accordingly, the guidelines offered, using the same categories used in the smoke section, are much briefer and reflect the level of current knowledge.

EFFECT OF ENGINE SIZE AND APPLICATION ON ODOR

The selection of diesels for reduced odor involves the entire vehicle design and goes beyond engine type or size. Broadly speaking, incomplete combustion brought about by inadequate air-fuel ratio, inadequate fuel injection, inadequate time for the burning process, insufficient temperature to promote complete combustion, incorrect fuel, incorrect speed, etc., are all factors that may influence the odor from engines.

Experience indicates that engines operated in highway-type applications in vehicles equipped with vertical stacks produce less noticeable odor than that from diesel-powered vehicles equipped with horizontal exhaust pipes. The same engine has also been shown to produce less odor when operating under highway-type conditions than in the city-type stop-and-go service. Although not all the reasons for this are understood, engine temperature and engine speed may have a bearing. Engine size, i.e., displacement and power output, does not influence exhaust odor as much as it affects smoke. At low or high idle (zero power output), however, some engines produce a noticeable odor but no visible smoke. Odor levels from four-stroke turbocharged engines are not generally different from those from naturally aspirated four-stroke engines.

The location and placement of the exhaust pipe does have a gross effect on odor. The quantity or quality of odorous emissions is not reduced, but the gases are dispersed and sometimes are less noticeable to the public. For this reason, vertical stack arrangements have been found to result in less perceptible odor than low-to-the-ground, or horizontal, discharges.

CAN ENGINE DERATING HELP TO MINIMIZE ODOR?

Both field and laboratory experience indicate little advantage in engine derating for the sole purpose of reducing odor. Normally, the effects of a moderate amount of derating in a well-maintained properly adjusted engine are difficult to perceive. Speed and power variations within the operating range of the engine seem to have only a slight effect on odor.

FUEL SYSTEM MAINTENANCE AFFECTS ODOR

Engine maintenance also can have an effect on odor. Depending on the engine type, fuel injection characteristics can have as much effect on odor as they do on smoke. In most instances, improvements in combustion reduce both smoke and odor.

Most manufacturers of automotive engines have very active development programs aimed at reducing exhaust smoke, odor, and other emissions; and from time to time improved products can be incorporated into older engines. As an example, the crown-type S fuel injector used in older Detroit Diesel 71 Series engines can be replaced with needle-type N injectors with reduced smoke and odor. Recently, an improved version of the N-type injector was put into production and is currently furnished in new engines. It is possible to achieve almost the same improvement in odor by replacing, at a nominal cost, the S-type injector (used in many of the existing engines) with the N-type injector. The reduction in odor possible with this change is shown in Figure 14.



Figure 14. Effect of injector type on odor

An injector with deteriorated spray pattern and cutoff may be a cause of significant levels of odor. For example, if fuel is injected into the combustion chamber after the normal cutoff point, it may be only partially burned. During deceleration of certain engines, a fairly pungent odor can be observed if the injectors are badly worn and do not positively cut off fuel. The effect of the late injection on odor production has yet to be investigated; however, it is not expected to be significant. It is fairly common for diesels to produce higher odor levels in the winter than in the summer, or in cold climates relative to warm climates. Overcooling may increase odor. The use and proper maintenance of high-temperature thermostats, thermostatically controlled radiator shutters, or variable-speed, thermostatically controlled fans are all techniques by which engine temperatures may be controlled at an optimum level.

INDUCTION AND EXHAUST SYSTEM MAINTENANCE AFFECTS ODOR

The induction system has a significant effect on odor in some applications and engine types. A seriously restricted inlet (Figure 15) may result in exhaust products of a highly malodorous nature.

Many fleet maintenance departments have established internal fleet maintenance procedures, preventive maintenance schedules, and service policies based on the manufacturers' recommendations and service manuals, as well as their own direct experience. The result is an individualized approach, tailored closely to the fleet application and need. Service bulletins concerning parts and procedural changes are published by the manufacturer and should be incorporated into the fleet maintenance procedures. Close supervision of the mechanic is usually effective in keeping odor as low as possible with engine maintenance. Where smoke and odor control is not now emphasized, a continuing program of information, education, and training advocating clean, clear exhaust is recommended. An incentive program or other recognition has, when carefully applied, demonstrated management's concern about exhaust emissions and resulted in better odor and smoke control.

EFFECT OF DRIVER TECHNIQUE ON ODOR

Just as the driver can influence the amount of smoke from his vehicle, he is able to reduce odor under certain conditions. Road adjustment of the engine fueling system to increase power not only increases the smoke output, but can increase odor as well. There is, therefore, a double reason for *not* making such adjustments. To minimize odor, it is normally helpful to keep the engine speed within the manufacturer's recommended operating speed range (Figure 16). By keeping the engine speed within the recommended range, smoke may also be reduced. It is also important to keep the engine temperature up, particularly during cold weather.

Another way the driver and *only the driver* can help to minimize odor (Figure 17) is to minimize idle and light-load operation. Unburned fuel and products of combustion from some engines condense in the exhaust, particularly during warmup or shortly after engine startup, and a more intense odor may result. A good rule is to start the engine and get it under load as soon as practical. Idling the engine generally does little to warm up the engine; it merely "loads up" the combustion chamber with unburned fuel, which may dilute the lubricating oil. Local delivery operation is



Figure 15. Ugh! me needum more air!

particularly acute in this regard. This type of operation usually includes substantial idle, either at the end of the run or intermittently at delivery points. It is recommended that the engine be shut off instead of being permitted to idle for extended periods.



Figure 16. Time to speedum up!

Driver training and education is important in an overall program to reduce vehicle odor and smoke. Most vehicle manufacturers publish handbooks describing recommended driving procedures. Encouragement by

management to develop driver attitudes conducive to less smoke and odor is an effective way to implement a program to improve the appearance of a fleet and reduce complaints or citations. Driver awareness of his potential for reducing odor and smoke must become a natural habit. Successful efforts have included such items as having drivers on the road watch other trucks in their fleet for excessive smoke. In conjunction with maintenance alertness during operation near



Figure 17. Me needum kid gloves for this job!

depots, this can be an unbeatable team if everyone works together. Management must take the initiative to obtain cooperation of both operation and

maintenance. Scheduling should not be so critical, or replacement units so overworked, that a "smoker" or a malodorous vehicle cannot be brought in for a check after being reported.

EFFECT OF TYPES OF FUEL ON SMOKE

In general, engines are optimized by the manufacturer to operate with either Number 1 or Number 2 fuel. Operating an engine optimized for Number 1 fuel may result in a more intense odor when it is operated on a Number 2 fuel. For example, a heavier, burnt-smoky, and sometimes more acrid odor has been reported from a municipal bus optimized for Number 1 but operating on Number 2 fuel. Less of the usual kerosene-type fuel odor was present, however. Studies of fuels with widely different properties and impurities have not pinpointed specific cause-effect relationships.

Additives for controlling odor may be classed as maskants (Figure 18—hides one odor with another odor) or counteractants (react with odor to form another odor or destroy the initial odor). Many operators have found that the use of odor additives, principally the maskant type, has helped to reduce complaints. Although laboratory tests have not shown a reduction in odor intensity, it may be that through an active public information program, the modified odor can be made more acceptable. In addition to the cost, the major disadvantage of the maskant may be the creation of an odor that may be more unpleasant to some people than the original odor. No unusual engine difficulties or maintenance problems have been reported when using such additives.

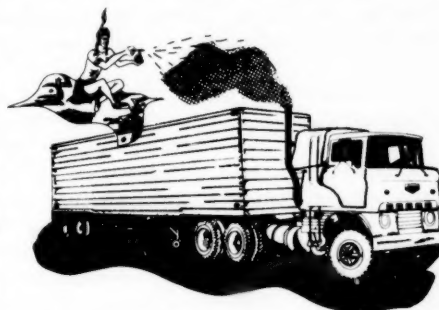


Figure 18. Maybe de-stinkum help!

Most diesel manufacturers have specific fuel recommendations for satisfactory engine operation. In addition, marketers of diesel fuel are helpful in matching the fuel specification to the particular engine and job application. The advice of both the engine manufacturer and the refiner should be obtained when determining fuel specifications for purchase, especially for abnormal climatic conditions or unusual duty cycles. Some engine manufacturers specifically warn against use of fuel additives other than those they have approved; in some cases, the engine warranty may be jeopardized by the use of additives.

EFFECT OF CONTROL DEVICES ON ODOR

Control devices for diesel odor include catalytic mufflers and many of the methods proposed to reduce smoke. Catalytic mufflers of the precious-metal type have been effective in reducing odor. Because of the dependence of reaction rates on exhaust temperature, the universal application of even the best catalytic muffler is not practical. In some applications such as stop-and-go city delivery, catalytic mufflers are only partially helpful in reducing odor. The approach has proved more effective under conditions of high exhaust temperature and nearly constant exhaust flow typical of a stationary engine or line-haul vehicle. Most fleet operators have felt that the initial cost of equipment and installation (as much as \$500.00 on some vehicles) and the cost to operate and maintain them do not justify use of catalytic mufflers except when extended operation in confined, unventilated, areas is required. Even then, the exhaust odor and irritants may be reduced less than 50 percent. Some designs required periodic or even continuous burnoff of contaminants to renew the catalyst surface and maintain performance. This means additional equipment and operating expenses and, in some applications, the regeneration procedure could present a safety problem. Further research and development will be necessary to determine the full potential of catalytic mufflers as well as make them usable on a large variety of motor vehicles.

As mentioned earlier, the placement and direction of vehicle exhaust stacks can have an important effect on the odor noticed by the pedestrian or motorist. More than merely diluting the exhaust, the odorous gases can be directed away from the observer. Though this does not destroy or reduce the total amount of odorous materials, the nuisance effect can be reduced. From three to ten times the atmospheric dispersion can be achieved by using a vertically directed stack terminating 12 feet above the road instead of a horizontal discharge 1 foot above the road. To reduce the noticeability of odor, straight vertical stacks terminating as high as practical above the road are recommended.

Some operators have found that in certain stop-and-go operations, the use of throttle-opening delays or dash pots to control the rate of acceleration has reduced odor and smoke emissions. Fuel injector design seems to have an important bearing on odor. This area offers potential for further reductions in both odor and smoke. As an example, new, improved fuel injectors reduced odor and smoke by about one-third in several low-compression two-stroke engines and can be accomplished at a nominal cost per injector.

Other control devices such as afterburners and wet scrubbers have been proposed. Direct flame incineration, though successful in some stationary applications for control of odor, has not been applied to mobile installations. Variations in exhaust flow and the variety of engines and applications are seen as disadvantages along with probable cost and safety factors. Wet scrubbers are even less practical because of the weight and space needed to

handle the large quantities of high-temperature exhaust without developing excessive backpressure.

Promulgation of Federal standards for diesel exhaust odor will require improved means for measurement and expression as well as feasible means to effect control. Efforts are under way by both industry and government to develop a better understanding of odor and its measurement.

SUMMARY OF RECOMMENDATIONS

Odor and smoke from diesels basically are problems in public relations. A team effort by everyone involved in the application and purchase, operation, maintenance, and driving of diesel-powered vehicles cannot help but achieve the goal of minimum odor and smoke. The following summarizes the suggestions offered in this Guide.

1. Since air-fuel ratio has the greatest effect on smoke from the diesel engine, any agent that tends to reduce this ratio either by excess fuel or insufficient air will lead to more smoke and should, therefore, be avoided.
2. Engine derating, the method usually employed to reduce smoke, is recommended and should be considered as a matter of procurement policy.
3. Vehicle and engine maintenance programs must include a continuing campaign against faulty fuel injectors, clogged air cleaners, and incorrect adjustment of injectors.
4. Turbocharging can be utilized to minimize visible smoke during operation at high elevations. New engines may be procured with this feature, and kits may be obtained from some manufacturers to modify existing naturally aspirated engines.
5. Odor and smoke can be reduced from certain two-cycle engines by the use of improved needle-type unit injectors instead of the crown-type injector. Use of the needle injector in the older E-type engine may reduce odor and smoke to the level emitted from the N-type engine. This recommended conversion can be accomplished at a nominal cost per injector.
6. Drivers should develop those driving habits that are known to minimize odor and smoke emissions. Drivers should, for instance, avoid excessive engine idle and underspeeding (lugging). Drivers should use a rear view mirror aimed at the exhaust outlet so that they are aware of excessive smoke emissions. An active and continuing driver education program should be instituted to encourage drivers to operate their vehicles in a manner that produces the least possible amount of smoke and odor.

7. The location and direction of the vehicle exhaust stack or pipe can make a significant difference in the noticeable and potentially objectionable aspects of smoke and odor. To reduce the noticeability of odor, a straight vertical stack, terminating as high above the ground as possible, is recommended. In some stop-and-go applications in public areas, a horizontal, low-to-the-ground exhaust has been found superior when used with well-maintained equipment to reduce fallout of soot.
8. Fuel should be selected to conform to the specifications recommended by the manufacturer of the engine.
9. Fuel additives being marketed for reduction in diesel odor and smoke should not be used unless they are acceptable to engine manufacturers.